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A critical analysis of the photovoltaic power industry in China – From diamond model to gear model

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ABSTRACT

The solar photovoltaic (PV) is an emerging renewable energy technology. With massive resource potential and commercial prospects, the development of the Chinese PV power industry is exceeding expectations. China's total PV power installations will account for 5% of the total electric power capacity by 2050. A diamond model approach is adopted in this study to identify and analyze factors that have significant impacts on the development of China's PV power industry. These factors include: factor conditions, demand conditions, chance, firm strategy, structure and rivalry, related and support industry, and government. Each factor identified in the model affects the competitiveness of the whole PV industry from a different angle. Therefore all factors ought to be strengthened for the long-term development of PV industry. A gear model is developed as a result of diamond model analysis. This model provides a useful tool to show the dynamic interactions among all factors affecting the development of the Chinese solar PV industry.

Contents

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1. Introduction

The rapid development of global economy creates a massive energy demand. The depletion of the fossil fuel resources has made the renewable energy becoming an important alternative with its widely distribution, renewable, cleanness, safety, and enormous amount [1]. The solar energy plays a significant role in the family of renewable energy. In general, there are four ways of utilizing the solar energy, i.e. solar photovoltaic (PV) power generation, solar thermal electric power generation, solar water heaters, and solar houses. The decentralized, independent distributed approach used to be the most popular way to utilize PV power. In recent years, the Grid-connected PV Generation (GPG) has become more popular where the GPG installed capacity is surpassing the independent distributed PV power globally. According to the Greentech Media Research, the global PV cell production is 7.1 GW and 10.7 GW in 2008 and 2009, respectively [2]. From a long-term perspective, the solar PV power will occupy bigger share in the energy mix. According to the European Joint Research Center's forecast, the solar PV power generation will account for more than 10% of the world total electrical supply in 2030, and more than 20% and 60% in 2040 and 2100, respectively.

China is the second largest country in terms of energy consumption. The PV power generation will play a critical role in China's energy strategy. According to China's Medium and Long-term Development Plan for Renewable Energy, China's total PV power installation will reach 300 MWp by 2010, 1.8 GWp by 2020, and 1000 GWp by 2050 [3]. According to the Chinese Electric Power Research Institute's forecast, renewable energy will account for 30% of the total installed electricity capacity in China by 2050, where solar PV will account for 5% of the total renewable energy installed capacity [4].

In China, there are more than 10 PV cell manufacturers and the total production of the solar cell exceeded 1200 MW in 2007, accounting for 35% of world output, ranking the first globally [5,6]. However, the Chinese PV power generation industry is not issue free. The main issues are: the productions of PV cells mainly rely on imported silicon materials [7], and the high GPG cost.

On one hand, China's PV power industry has the advantages of abundant solar energy resources and the Government supporting policies. On the other hand, China's PV power industry has not been developed maturely due to the high cost and lack of core technology. This study adopts a diamond model approach to analyze the situation of the PV power industry in China. Main focus is placed on investigating how main elements in the model affect the competitiveness and development of China's PV power industry. As a result, a gear model is developed in order to highlight the interactions of these main elements.

2. Diamond model

Porter's diamond model is an effective methodology to analyze the competitive advantages of a national industry. As shown in Fig. 1, a diamond model consists of four major components, i.e. factor condition; demand condition; related and support departments; and firm strategy, structure and rivalry, as well as another two accessorial factors: government and chance [8]. Covering capital resources, natural resources, infrastructure, the "factor condition" often provide initial advantages. As measures of sophisticated and demanding local customers, the "demand condition" influence the pace and direction of innovation as well as product development. The "related and support departments" considers the supply chain aspect of an industry, e.g. the accessibility to quality suppliers. And firms often enjoy advantages such as cost efficiency and innovative inputs if a mature support industry exists. The "firm strategy, structure and rivalry" are the local context and rules that encourage investment and sustained upgrading, the incentive systems across all major institutions, and the open and vigorous competition among locally based rivals [9].

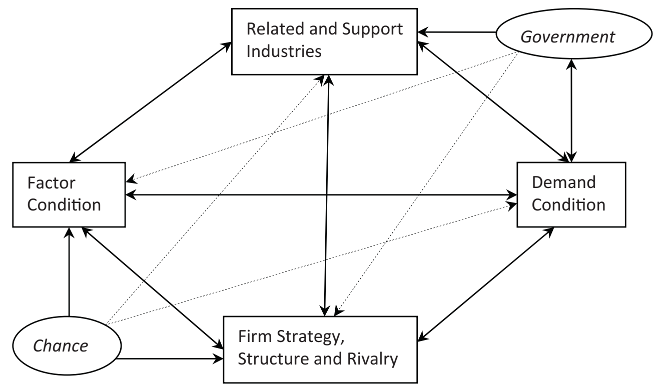

Fig. 1. Diamond model.

The diamond model fully summaries the factors that affect the competitiveness of an industry. The model highlights the firms' strategies and the government behaviors so that how an industry can improve its competitiveness according to the identified factors. This paper analyzes China's PV power industry using the diamond model. The components and contents of the diamond model are shown in Table 1.

3. Diamond model analysis

3.1. Factor condition

3.1.1. Potential solar resource

According to the Chinese Weather Bureau, China has abundant solar energy resources. The full land surface has an annual solar radiant energy of 1.7×10^{12} tce. More than two-third of the country receive an annual solar radiation over 5.02×10^6 kJ/m^2 and over 2000 annual sunshine hours [10,11]. Provinces located in different latitudes have different level of solar irradiation as shown in Fig. 2 [12].

3.1.2. Generation costs and the on-grid power price

Depending on whether or not connecting to the grid, the PV power generation can be divided into two systems, i.e. the GPG and the stand-alone PV system. Generally, the costs of the GPG cover three components: the PV module costs, the grid connected system component parts costs (including grid-controlled inverter costs and trestles costs), and the installation costs [13]. The GPG grows slowly compared to other PV applications in China. The GPG accounted for as low as 0.3% of the total utilization of solar energy in 2007 [4]. The

Table 1
Component and content of the diamond model for PV power industry of China.

Components	Contents
Factor condition	Solar resource potential, generation costs and on-grid power price, programs and projects, and technology
Demand condition	Overall market, installed capacity, and on-grid PV systems
Firm strategy, structure and rivalry	Industry rules, and industry competitions
Related and support departments	PV cell manufacturing, and grid construction industry
Government	Legislation, policies, financial incentives, and taxation
Chance	Industry advantages, and industry challenges

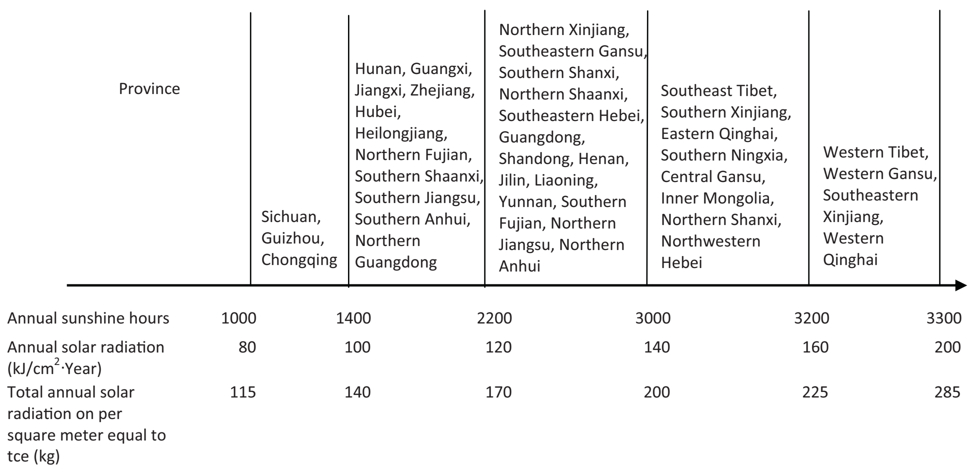

Fig. 2. The solar resource in different provinces of China.

high cost of PV cells and the high on-grid price of the PV power are responsible for the slow take-up of CPG in China:

(1) The high cost of PV cells

The cost of solar PV cell is 40–45 Yuan/kWh in 1980s when the China's PV industry started up. In 2000, China's mono-crystalline silicon cell cost was 42–47 Yuan/kWh and amorphous silicon solar cell cost was 23–25 Yuan/kWh. In 2009, the cost of solar cells dropped to 10–75 Yuan/kWh [14]. At present, solar cells cost accounts for 60% of the total cost of the PV generation. In China, the current price for PV modules is 32 Yuan/Wp, which is 15.8% lower than that of 2005 level.

(2) The high on-grid price of the PV power

In 2007, the average on-grid price of PV power is 4 Yuan/kWh [15]. This price has dropped significantly, however, the average on-grid price of PV power is still significant higher than that of wind power, nuclear power, coal-fired, and hydropower in 2009 [16] (see Table 2). In 2009, the on-grid price of China's PV power is about 1.5 Yuan/kWh, which is still too high from end user's perspective. By contrast, the retail price of the conventional fossil resource in China is as low as 0.5 Yuan/kWh. The cost of China's PV power generation can be reduced substantially by means of technological innovation or the energy policy support so that the solar power generation can gain further development in a large scale. The substantial programs as well as policies have been put forward to encourage the PV power development in China, so as to advance its rich solar energy resource and to utilize its great production capacity [17].

Table 2
China on-grid electricity price in 2009.

Type	On-grid power price (Yuan/kWh)
Wind power	0.56
PV power	1.5
Nuclear power	0.44
Coal-fired power	0.35
Hydropower	0.265

3.1.3. Programs and projects

Rural areas in China (such as in Tibet, Qinghai, Inner Mongolia, Xinjiang, Ningxia, Gansu, Yunnan, and Sichuan) generally have richer solar resources. However, lack of infrastructure to connect the PV power generation to grid presents a significant challenge for the development of solar PV in these areas. Therefore, major PV power projects are implemented to solve these issues. The Chinese Government actively supports the development of PV power and commissions a series of PV power developments. For example, the "Western regions electricity program for rural areas without electricity" was executed in early 2002. Majority of these projects are PV power generation. In 2005, the Yangbajing grid-connected solar PV power station was completed in Tibet with an installed capacity of 100 kWp. It is the first PV power station connected to the 110 kV power grid in China. In 2006, some demonstration PV generation projects were implemented to motivate solar PV developments. For instance, Shanghai has built 7 PV power demonstration plants. In 2006, some provinces laid down a series of programs to support the PV power industry. For example, Jiangsu province had released a plan that 5 international solar PV manufacturing corporations will be formed province-wide, and making the PV cells production scale reach 1200 MW. A number of solar PV power plants were constructed in Sichuan, Ningxia, Jiangsu, Shaanxi, Gansu and Yunnan in 2007 and 2008. In 2009 and 2010, the solar PV developments gradually turn to the large-scale grid connected power plants. Table 3 lists selected major PV power projects in China.

3.1.4. Technology

Technology is one of the core competitiveness factors for the PV power industry. The technological level affects the cost of PV power directly. The research and development (R&D) of China's PV power technology started up in 1960s. At present, China has mastered

Table 3
Selected major PV power projects in China (2009–2010).

Project Name	Year	Province	Total installed capacity (MW)
Shizuishan PV power station	2010	Ningxia	50
Zhangye PV power project	2010	Gansu	10
Xigaze PV power station project	2010	Tibet	30
Xiaowutai, Youyu power station Stage I	2009	Shanxi	10
Dunhuang GPG project	2009	Gansu	10
Northeast first PV power station	2009	Liaoning	0.3
Delingha GPG station	2009	Qinghai	10
Ge'ermu GPG station	2009	Qinghai	5
Ge'ermu harsh desert connected PV power station	2009	Qinghai	200

Table 4
The electricity sales from 2004 to 2009 in China.

Year	Electricity sales (10^{12} kWh)	Annual growth rate
2004	1.7384	
2005	1.9554	12.5%
2006	2.2825	16.7%
2007	2.6430	15.8%
2008	2.8418	7.5%
2009	3.0586	7.6%

some key technologies of PV cells and applications. Due to advanced technologies, the efficiency of PV cells has been improved and the PV power cost has been reduced significantly.

However, there are some technology issues associated with the PV industry in China. First, the DC/DC (Direct Current) circuit topology can track the Maximum Power Point (MPP) of the PV system. The conventional Buck and Boost and Bust–Boost circuit is used to acquire the MPP of PV, however the efficiency is low during the course of tracking MPP. In 2010, the converter efficiency can achieve higher than 90%, however it is still an issue as the solar PV price is very high [18]. Second, the PV cells material technology restricts the PV industry development in China. The silicon purifying is a high technology and the purity of silicon significantly affects the efficiency of PV power transformation. Third, there are severe environmental concerns as advanced technologies are required to deal with the toxic substances accompany with the silicon purifying. Currently, most of China's PV cells manufacturers purchase the technology license from overseas.

Similarly, there are some technology difficulties during the process of PV power connecting to the grid such as the energy storage issue. The stand-alone PV generate electricity system has a common drawback, where the output electric power of the PV power is unpredictable due to significant changes in climatic conditions. The hybrid system can partially overcome these problems. Some hybrid methods (such as the wind-diesel, the diesel-solar and the wind-solar hybrid systems) have been used to improve the quality of the electric power. However, the cost of wind-solar hybrid systems is very high. For example, the price of a set of wind-solar hybrid street lamp is more than US$4000, and the price of a set of conventional street lamp is about US$2200. Certainly, the price will descend with the technology innovation so that the wind-solar hybrid system has a great potential in the future [19].

3.2. Demand condition

3.2.1. Overall market

The electricity demand and supply in China has been increasing in the past 6 years as shown in Table 4. From the long term perspective, the conventional power is not able to meet the increasing electricity demand, where the rapid development of renewable energy power including the PV power will fill in this gap. Although China has rich solar resources, the geographical distribution of solar resources does not fit well with the national power load profile. There are rich solar energy resources in the desert and plateau areas of China. Coastal regions with heavy loads have insufficient solar resources, whilst the areas with abundant solar resources are in relatively smaller demand. This presents a significant challenge to deploy the PV power cost-effectively. Moreover, the areas with abundant solar resources are mostly distant from the power load centers, whereas the power grid construction is relatively weak. This tension has significantly restrained China's PV power development. Therefore, it is necessary to improve the power grid capacity to support the large scale PV power development.

Although the PV power price is much higher than the conventional coal-fired power, the PV power has its own competitiveness from long term perspective. China's coal-fired power plants are facing enormous pressures due to the rising prices of the fossil fuel. Although the scale of PV market in China is comparatively small, it is expected to grow drastically within the next 5 years in order to meet its targets of supplying 15% of total primary energy from renewable energy sources in 2020 [20]. As a newly developed renewable energy sector with a large potential and healthy commercial prospect, China's PV power industry is taking necessary measures to enlarge market demands as well as increasing technical and financial inputs. The sustainable and stable market demand will create conditions beneficial to the development of the industry.

3.2.2. Installed capacity

Since 1990s, China's PV power is developing rapidly where the installed capacity is increasing constantly. According to the statistics provided by the European Photovoltaic Industry Association, the newly installed capacity of the PV power in China grows at a high level from 2005 to 2009 [21], reaching 140% and 125% in 2006 and 2008, respectively. The cumulative installed capacity of the PV power generation mounted to 295 MW by the end of 2009. Fig. 3 shows the annual installed capacity and the cumulative installed capacity from 1976 to 2009 [18,21]. According to the Renewable Energy Mid-Long Term Development Plan, it is expected that there will be three to five desert power plants with an installed capacity of 1–10 MWp each being put into operation by the end of 2010, with a total capacity of 20 MWp [7]. Furthermore, the large-scale PV desert power plants will be given high priority from 2010 to 2020, where the total cumulative installed capacity in the desert is estimated to reach 200 MWp by 2020 [4]. The cumulative PV power installations will reach 1.8 GWp by 2020 and 1000 GWp by 2050 nationwide in China [7].

3.2.3. On-grid PV systems

The on-grid PV power is a global trend for the PV power industry development. In 2007 around 60% of solar cells over the world

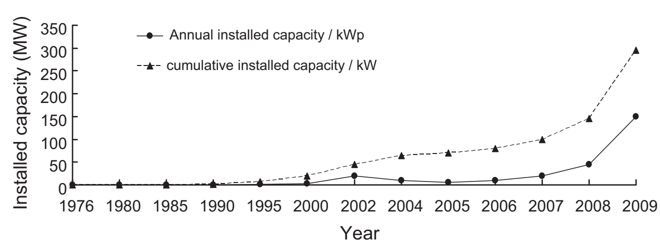

Fig. 3. The annual installed capacity and the cumulative installed capacity of the solar energy generating in China (1976–2009).

are used in the grid-connected power systems, mainly in on-grid PV systems in cities. In China, the on-grid PV power electricity price is about 3 or 4 times of the traditional power price. In fact, the PV power generation corporations will loss heavily without the financial support from the governments. Despite of cost disadvantages, China makes a series of plans to develop on-grid PV systems. It is expected that tens of large on-grid PV projects will be completed before 2020, where the total cumulative installed capacity will reach 700 MWp. The percentage of on-grid PV systems to the total PV systems will be increased from 21% by 2010 to 39% by 2020 [4]. However, the solar PV power generation is heavily influenced by the day and night change, weather conditions and the change of seasons. As the on-grid PV system is featured with instable load and frequency, it presents a significant challenge for the power grid to regulate the electricity load. Currently the installed capacity of on-grid PV power plants is only 140 MW. Lacking of the running data makes it difficult to explain the impacts of the large-scale PV power on the power grid. And lack of power grid infrastructures for connecting PV power plants to existing grid and lack of relevant technical standards and product testing capabilities are major factors restricting the on-grid PV power development [22]. To overcome these weaknesses, China is increasing the investment in smart grid, integrating the power grid planning with the power plant planning, and developing relevant technical standards.

3.3. Chance

3.3.1. Industry advantages

The growing tension between the energy supply and the demand may aggravate energy shortage issues, even rising to the national security level. There are a number of opportunities to China's PV power industry thankful to the improvement of related supporting policies, the PV power R&D and the personnel training. China has been working very hard on developing a low-carbon economy and utilizing cleaner, renewable resources. Consequently regions with rich solar resources will benefit to the PV power development. With the increase of fossil fuel prices, the PV power has become a promising low-carbon technology. Considering the strong support from all levels of governments, solar PV power will have a prosperous future in China.

In line with the rapid progress of the China's PV industry, opportunities and challenges coexist. The main opportunities of China's PV industry include: (1) China has abundant solar energy resources in its vast land [18]. (2) A series of policies and regulations have been released to encourage the development of China's PV power industry. (3) The demand of electricity is growing rapidly, and the PV power will play a more important role in energy mix. On a conservative basis, the total PV generation capacity will reach 1.8 GW in 2020 [7]. In fact, the PV power installations grow so rapidly so that it is expected that the cumulated installed capacity will exceed expectations, reaching 1 GW by 2011 [23]. (4) The cost of China's PV power is reducing due to the advanced technology.

3.3.2. Industry challenges

China's PV power industry is facing significant challenges in various aspects: (1) the resource distribution is severely imbalanced where regions with rich solar energy resources are normally distant from the load centers. (2) The on-grid power price constrains the development of China's PV power industry. It is difficult for the solar power generation to advance in a large scale until the technological advancement substantially reduces the cost of PV power generation [24]. Indeed, affordability of renewable energy remains a significant challenge despite enormous efforts by various levels of Chinese governments on renewable energy pricing [25]. (3) With the rapid expansion of the PV power manufacturing, the quality of the PV power equipment will be a significant challenge for the whole industry in China. It is vital to ensure the stability and reliability of PV power equipment as well as enhancing manufacturer's maintenance capability. (4) Lack of the technological innovation and the human resources chronically constraints the competitiveness of China's PV power industry. The skilled human resources with the knowledge and the hands-on experience on core technologies such as the PV cells manufacturing, the PV plants management, the testing and certification are desperately required, particularly on the PV cells manufacturing.

3.4. Firm strategy, structure and rivalry

The high price of raw materials, small scale markets, lack of product and technology standards and instable quality are constraining the sustainable development of China's PV power industry. In this rivalry environment, the common strategy adopted by most China's PV firms is to focus on the specialization, the differentiation and the technological innovation. If taking the specialization strategy, the company entirely concentrates on specializing one particular sector of the PV industry in order to meet any market changes. In terms of technological innovation strategy, PV enterprises devote for the research and development of the core technologies related to PV power. Those PV companies implementing the differentiation strategy focus on distinguishing from counterparts by means of branding and marketing of key products and technologies.

Moreover, China's PV companies can provide a more streamlined and efficient production process, shorter production cycles, better quality control and lower costs by means of a vertical integration strategy. Take the LDK Solar Co. as an example. Established in 2005 in China, LDK Solar is a large manufacturer of solar wafers in terms of capacity and a leading high-purity polysilicon and solar module manufacturer. The company has expanded its business to meet the solar industry's requirements for high-quality and low-cost solar materials and solutions. As a vertically integrated manufacturer and supplier of PV products, LDK Solar has more than 15,000 employees worldwide. In 2009, LDK Solar expanded the scope of its vertical integration strategy to cover providing solar modules to developers, distributors and system integrators. LDK Solar acquired the crystalline module manufacturing plant of Best Solar in February 2010 to bring the manufacturing capability in-house [26]. The vertically integrated manufacturing, the large scale production facilities, the diversified global customer base and the high-quality and high-efficiency products contribute toward the rapid growth of LDK Solar. This approach can be considered by other Chinese PV companies.

The developing potential of the PV power industry is massive however the industry standard is not comprehensive and the market access threshold is lower than the traditional power industry. As long as having certain amount of funds, many firm can enter the industry. As a result, there are hundreds of PV companies operating in China at the moment, whereas this number is increasing constantly. Above all, there is fierce competition among PV companies in China's PV industry.

3.5. Related and support industry

3.5.1. PV cell manufacturing

The PV power industry chain includes the PV equipment manufacturing, the PV power plants and the grid construction as shown in Fig. 4. The competitiveness of the PV power industry will largely depend upon the development level of all related and supporting industries. Currently the major types of PV cells include the

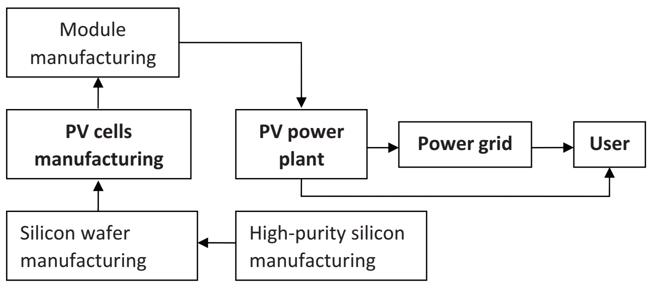

Fig. 4. PV power industry chain.

mono-crystalline silicon solar cells, the polycrystalline silicon solar cells, and the amorphous silicon solar cells. The mono-crystalline silicon and the polycrystalline silicon cells are superior to the amorphous silicon cells in terms of energy conversion efficiency and the service life. The polycrystalline silicon cells' efficiency is slightly lower than the mono-crystalline silicon however with lower price.

For all kinds of the PV cells, the silicon is the most important raw material, and the silicon for PV cells must be high purity. However the status of raw materials and overseas markets restricts the development of the China's PV industry [27]. As the main raw material for the solar PV cells, 95% of China's high-purity polysilicon materials rely on importing from overseas. Similarly, the core technology is largely monopolized by foreign manufacturers. This is the largest bottleneck for the China's PV cell manufacturing. However, in recent years with the increasing market demand, the domestic PV cell manufacturers expand production capacity rapidly. Taking the well-known enterprise Suntech Power Co. in Wuxi as an example, it is a PV enterprise which mainly engages in the crystalline silicon solar cells, the modules, the PV systems engineering and the PV applications' manufacturing, sales and services. In 2004, the Suntech has been ranked as the world top 10 manufacturers of the solar PV cells by PHOTON International and was ranked as the world top 5 at the end of 2005. Currently, its manufacturing capacity of solar cells is about 150 MW, becoming one of the top 4 production bases over the world. In particular, the volume of sales of Suntech's crystalline silicon module has ranked first over the world since the second quarter of 2010.

3.5.2. Grid construction industry

In China, the grid construction does not keep pace with the PV power development. From 2002 to 2007, the investment in the power generation increased from 74.7 billion Yuan to 322.6 billion Yuan at an average annual rate of 28%. At the same time, the investment in the grid system only increased at an annual rate of 9%, from 157.8 billion Yuan to 245.1 billion Yuan [28]. There are few regulations and instructions on how to connect the PV power to the grid. The PV power grid connection has not been standardized, whereas the PV power connection has not been considered fully during the power grid planning. To target this issue, the management regulations and the technical specifications should be formulated and stipulated to bring the PV power into the grid planning system. Similarly, the restriction to the PV power input allowed to the grid has become a bottleneck in the PV power development. The grid companies are constructing new infrastructures to support the connection of PV power. Similarly, it is imperative to clarify the relationship between the PV power development and the grid extension, ensuring the safety of both the PV power plants and the grid operation.

Fortunately, the GPG has been taken into consideration by the Chinese Central Government and some power generation corporations. Dunhuang grid connected PV power project is the biggest GPG in China. Located in Dunhuang, Gansu Province, its total capacity is 10 MW and the total investment is more than 73 million US$. This project is about 13 km from Dunhuang city, which can provide clean energy for the residents in the city. Other projects include the Chongming Island project in Shanghai with a total capacity of 1 MW and the Eerduosi project in Inner Mongolia municipality with the total capacity of 255 kW [29]. These projects have played a critical role to improve the local energy structure.

3.6. Government

3.6.1. Legislation

The government plays a key role to regulate the renewable power market, especially when the current industrial environment is not mature. The Chinese government has formulated a series of laws and regulations for the PV power development:

(1) The China Electric Power Law promulgated in 1995 is the first law to deal with the energy resource issues [30]. This law explicitly specifies that the government encourages and supports the electricity generation from clean and renewable energy resources. It also states the importance of developing renewable energy for the rural power development and agricultural power consumption.
(2) The Renewable Energy Law which was taken into effect in 2006 clearly stipulated that the renewable energy development will be given higher priority in energy developments [31]. It defines the obligations of various parties related to the grid, the power generation, R&D, the regulations and the standards. By the Law, implementation regulations were formulated covering 12 key issues including the pricing, the grid connection and the incentive policies [32].
(3) The China Energy Conservation Law promulgated in 2007 reaffirmed and reemphasized the strategic role of the renewable energy technologies for optimizing the utilization of energy resources, reducing emissions, and improving environment [33].
(4) The newly amended China Energy Conservation Law enacted in April 2008 helps to resolve the growing contradiction between the energy demand associated with the rapid economic development and the environmental degradation [34].
(5) The Renewable Energy Law (Amendment) which was promulgated in 2009 clearly states that the scientific and technological research will be commissioned by governments where the renewable energy industry development and utilization are given higher priority for the development of the high-tech industry [35]. The Central government takes it into the national science and technology development planning and the high-tech industry development plan, and allocates funds to support the relevant scientific and technological research, the application demonstration and the industrial development. This will promote the development and utilization of the renewable energy, as well as reducing the products cost and improving the products quality. By the law, China encourages companies and individuals to install and utilize the PV power system, and encourages the renewable energy connecting to the grid.

3.6.2. Policies

Apart from those laws, the China's government has released a number of policies to promote the PV power industry. Three most important policies to stimulate the commercialization of the renewable power projects are the Feed-in tariffs, the Tendering policies and the Renewable Portfolio Standards (RPS) [36]. The feed-in tariffs help to develop the renewable energy infrastructure more rapidly. The Tendering policies are helpful to acquire the competitive prices and to achieve the economic goal.

A series of policies have been promulgated by the Chinese Central Government:

(1) The Renewable Energy Price and the Cost-sharing Management Pilot Scheme promulgated by the NDRC in 2006 encourages end users to purchase the renewable energy electricity voluntarily, where a fixed solar power grid price is guaranteed by the government [37]. The standard PV power electricity price is instituted by the State Price authorities in form of the production cost plus the reasonable profit. The renewable energy levy is collected by the power grid enterprises which must be used for a special purpose.
(2) The Eleventh Five Year Plan for the Solar Industry Development promulgated by the NDRC in 2006 points out that the GPG and the small-scale PV power plants will be developed to solve the power shortage problem in remote places such as Tibet, Qinghai, Xinjiang and Inner Mongolia by taking advantage of local conditions. Similarly, China will build on-grid large-scale PV power plants in those places that have rich solar PV power resources, such as Tibet, Gansu, Inner Mongolia, Ningxia, and Xinjiang [38].
(3) The Medium-to-Long-Term Plan for Renewable Energy Development promulgated by the NDRC in 2007 proposes the construction of the solar PV power projects focusing on building small-scale PV power plants to solve electricity supply issues in rural areas. The target is to take the total capacity of the solar PV power plants nationwide up to 1.8 GWp by 2020 [7].

Similarly, some provincial governments released supporting policies to promote the solar PV power development. For instance, the Jiangsu provincial government issued implementing notices on solar PV industry in 2009. It stipulated that the government will devote to develop the solar power industry by means of issuing supporting policies, developing relevant standards and providing incentives [39]. Other provinces such as Hebei, Shanghai, Zhejiang, Shandong and Fujian are taking the similar approach.

3.6.3. Financial incentives

The PV power development requires vast upfront investment with a long payback period. A growing PV power industry largely depends on the financial support by Chinese government.

“Interim Measures for the Management of Subsidies for Solar PV Buildings” was promulgated by the Ministry of Finance in March 2009 [40]. The Measures support the application of solar PV power in buildings which involves high level of technologies and large capacity. It stipulated that the government will allocate the one-off subsidy of 20 Yuan/Wp for the building PV system with a capacity of more than 50 kW. This is the first ever measures in China which clearly stipulated that PV companies will enjoy subsidies even though there is limited amount of subsidies.

“Interim Measures for the Management of Subsidies for Golden Sun Demonstration Projects” was promulgated by the Ministry of Finance in 2009 [41]. According to the Measures, the Ministry of Finance will arrange subsidies from renewable energy special funds to support various types of PV technology in the field of the model application and the key technology. The subsidies include: the grid power projects subsidy, the independent power projects subsidy, the PV technology industrialization demonstration project subsidy and the infrastructure construction of the PV power generation subsidy. The measures focus on subsidies for the PV power generation project which will effectively promote China’s PV market share. According to the Measures, the Central Government will provide subsidies for those grid-connected PV power projects accounting for 50% of the total project investment and the independent PV power projects in rural power shortage areas accounting for 70% of the total project investment. The Measures greatly reduce the risk associated with solar PV power projects from the developer’s perspective. Local governments can make investment decisions in short term. The Measures also encourage investment in PV power developments. PV cell manufacturers are encouraged to gradually explore the domestic market in order to avoid the dependence of importing PV highly purified cells from overseas.

3.6.4. Taxation

There are three major taxes affecting China’s PV industry, i.e. the value added tax (VAT), the customs duties, and the business income tax. The State Council started to exempt the import tariff and import VAT within the specified scope since January 1998. Those PV power developments involving importing PV cells from overseas can enjoy this taxation exemption.

“The Catalogue of Industries, Products and Technologies Encouraged by the Central Government” promulgated by the State Council in 2000 and amended in 2005 states that the solar PV power projects are exempted from the customs duties and import VAT [42]. Other administrative measures include “Interim Provisions for Promoting the Adjustment of Industrial Structures” promulgated by the State Council in 2005 [43], “The National Catalogue of Encouraging Equipment and Products of the Environmental Protection Industry” promulgated by the NDRC and the Ministry of Environmental Protection in 2010 [44], and “The Guide of Priorities for the Development of High-tech Industry” promulgated by the NDRC in 2010 [45]. According to these measures, renewable energy related enterprises enjoy the taxation preferential policies in terms of equipment depreciation. In particular, the income tax rate is reduced to 15% if solar PV developments are foreign invested in coastal economic open zones, special economic zones, and economic and technological development zones.

4. Gear model for improving the competitiveness of China’s PV industry

A diamond model approach is adopted in this research to analyze the factors affecting the competitiveness of the PV power industry in China. All these factors are grouped into six categories, i.e. factor condition, demand condition, firm strategy, structure and rivalry, related and support departments, government and chance. These factors are: solar resource potential, generation costs and on-grid power price, programs and projects, technology, overall market, installed capacity, on-grid PV systems, industry rules and industry competitions, PV cell manufacturing, grid construction industry, legislation, policies, financial incentives, taxation, industry advantages, and industry challenges. All these factors affect the competiveness of China’s PV industry from different angles. Similarly, the interactions between these factors form a joint force to improve the industry competitiveness. A gear model is developed to highlight this process (see Fig. 5).

Porter’s diamond model is a dynamic model where all components are changing continuously. Therefore, the application of this model needs to be dynamic as well. The gear model provides a useful tool to analyze and understand this dynamic process of the development of the PV industry.

During this improvement process, the main force comes from China’s PV industry its own and the government plays a role as coordinator and motivator. Similarly, the government motivates the related and support department including the PV cell manufacturing and the grid construction industry which is another promoting force for the improvement of competitiveness. The development balance of the three parts is important for the improvement of the whole industry. Thus, the strategies and plans of the three parts should fit in the dynamic progress in order to further improve the competitiveness of China’s PV power industry.

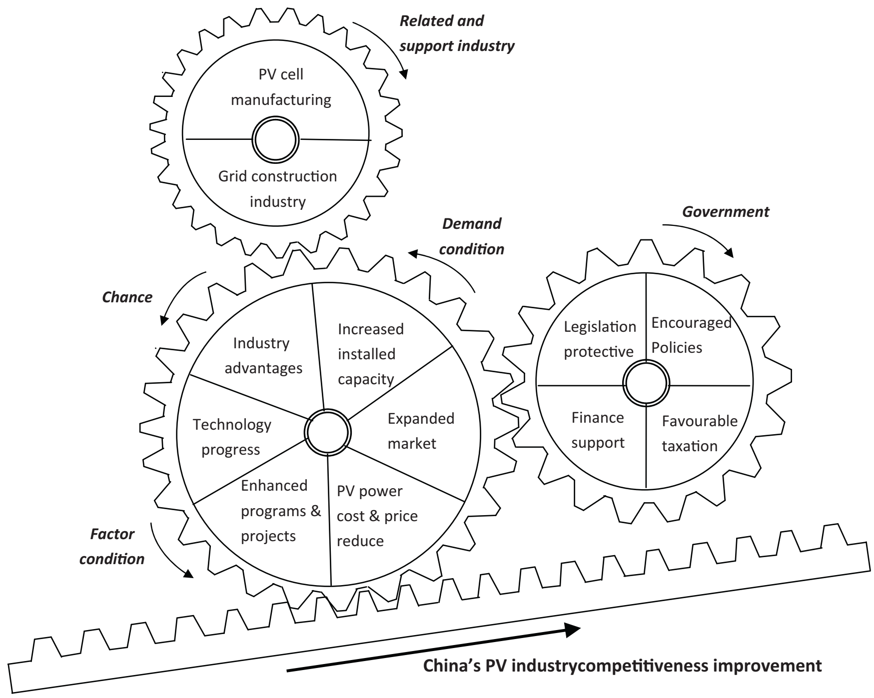

Fig. 5. The gear model of the dynamic competitiveness improvement progress of China's PV industry.

5. Conclusion

This paper analyzes the competitiveness of the PV power industry of China via a diamond model approach. China is paying attention to the industry's constantly changing environment, and formulating strategies accordingly. The results show that China's PV power industry has great potential in the future. There are huge solar energy resources in China. A number of programs and projects have been carried out to promote the PV power developments. The generation costs and the on-grid power prices of the PV power are high, presenting a significant challenge to the sustainable development of the local industry. Other challenges include: fierce competition, lack of infrastructure for connecting PV power to the existing grid and lack of core technologies. It is imperative to enhance the competitiveness of China's PV power industry by establishing a comprehensive PV power industry chain and improving the independent innovation capacity. The government plays a vital role to foster an environment to promote the development of the PV power industry in China by means of supporting policies, legislations and financial incentives. In order to improve the competitiveness of the PV power industry, it is necessary to strengthen all elements in the diamond model so that a positive interaction can be achieved. The interactions among these factors are dynamic and complicated. The gear model is developed in this study to understand this dynamic process, providing a useful tool to policy makers and industry practitioners.

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